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THE DISTRIBUTION AND ELIMINATION OF ERRORS IN THE MAZE

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In the solution of the maze problem, animals do not distribute their errors equally between the various cul de sacs; apparently these blind alleys do not offer equal incentives to entrance. Neither do the cul de sacs present the same difficulty in mastery; the tendency to enter certain alleys is eliminated much sooner than in the case of others. The principles determining the relative frequency of entrance into the various alleys, and the factors governing the order of their elimination are inadequately known.

Vincent[1] has published data concerning the first problem. Hubbert[2] and Vincent[1] have investigated the second question, and Watson,[3] on the basis of Hubbert's results, has contributed to the discussion.

Watson contends that if food satisfaction is a causal agency in selecting the true path and thus eliminating the cul de sacs the latter part of the maze should be mastered first; hence the cul de sacs should be eliminated in the order of their nearness to the food box. He therefore concludes that food satisfaction can not be regarded as a selective agency because only seven of Miss Hubbert's eighty-four rats eliminated the six errors in the exact order of their spatial contiguity to the food box.

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[1] Vincent. The White Rat and the Maze Problem. *Jour. Animal Behav.*, **5**, 367-374.

[2] Hubbert. Elimination of Errors in the Maze. *Jour. Animal Behav.*, **5**.

[3] Watson. Behavior, p. 268.

Watson's argument, to my mind, contains two fallacies: 1. A causal factor can mediate an invariable result (without any exceptions) only under the ideal condition that it is the only causal agency involved. Needless to say such a condition does not obtain in any science, to say nothing of animal behavior. The ideal effect of any hypothetical cause is always somewhat altered, distorted, or even obscured by the influence of other factors which can not be controlled. Hence general tendencies and results must be utilized as diagnostic symptoms in the search for causal conditions. Viewed in this light, Hubbert's results support rather than disprove the efficacy of the alleged principle of selection, for the general trend of the order of elimination is that of the spatial contiguity of the alleys to the food box. According to my computations, 80% of her rats eliminated the 6th error before the 5th, 50% the 5th before the 4th, 47% the 4th before the 3rd, 73% the 3rd before the 2nd, and 70% the 2nd before the 1st. Determining the average number of trials necessary to eliminate each cul de sac, the order of elimination for the entire group was 6-5-3-4-2-1, where the successive errors are numbered in order from the entrance. This order gives by the rank method a positive correlation of .943 between quickness of elimination and propinquity to the food box. The average number of trials necessary to eliminate the last three errors was less than that for the first three for 90% of the rats. Surely there is a very pronounced tendency for the errors to be mastered in proportion to their nearness to the food box, and the deviations from an *exact* correlation for each rat may well be due to the operation of other causal agencies. The existence of other efficacious agencies, viz., recency and frequency, is admitted by Watson. 2. Granted that food satisfaction is the only effective agency involved, yet a *perfect* correlation between speed of elimination and nearness to the food box, as demanded by Watson, would not obtain. According to the hypothesis the order of elimination will be determined, not by the spatial arrangement of the cul de sacs in relation to the food box, but by the temporal relation of the errors to the food experience. The temporal order in which the cul de sacs are entered is not the same as their spatial order in the maze. Not all cul de sacs are entered on each run. An animal may enter alleys 1, 3, and 5, and skip 2, 4, and 6. The matter is further complicated by the phenomenon of returns. The tendency to return toward the entrance box is very persistent during the early stages of learning, and in any trial we may have a temporal order of 1-3-6-1-2-3-4-5-4. According to the hypothesis this trial will tend to eliminate alleys 3, 4, and 5 prior to 6.

Hubbert's results, however, neither prove nor disprove the efficacy of food satisfaction as an eliminative agency. Although a high degree of correlation obtains between rate of elimination and nearness to the food box, one should still refrain from generalizing on the basis of one maze. Different maze patterns may give other results. A correlation between two factors does not always indicate a causal relation between them; both may be the result of some more fundamental condition.

This paper presents data on two mazes, and in addition Miss Vincent has kindly furnished me records for six mazes. A cul de sac was considered eliminated when but one entrance was made in ten successive runs. The number of trials necessary to eliminate each alley was determined for each animal and the average number of trials for the group was thus computed for the various cul de sacs. These values constitute the order of elimination for the group. This temporal order of mastery was correlated by the rank method with the spatial arrangement of the alleys in relation to the food box. Table I designates the various mazes, gives the number of cul de sacs in each, the number of rats employed, and the correlation data for each maze pattern. Mazes I-a to I-e have the same pattern, a slight modification of the Hampton Court arrangement; they differed only in the arrangement of sensory factors. I-a presented a uniform sensory interior; I-b had the true path painted white and the blinds black; I-c had the true path painted black and the blinds white; in I-d an olfactory trail was laid in the true path, while the trail was inserted in the cul de sacs for I-e. II-a and II-b were alike except that the alleys of II-b were without sides. The records for the above mazes were obtained by Miss Vincent. Mazes III and IV were somewhat similar in pattern but radically different from patterns I and II. Maze V refers to the circular maze used by Miss Hubbert whose data are given for comparison.

TABLE I

CORRELATION BETWEEN QUICKNESS OF ELIMINATION AND NEARNESS TO THE FOOD BOX

Maze	Number of cul de sacs	Number of rats	Percentage of correlation
I-a	7	10	.607
I-b	7	10	.714
I-c	7	9	.178
I-d	7	6	—.643
I-e	7	6	—.358
II-a	7	6	.750
II-b	7	6	—.822
III	11	16	.563
IV	9	15	.666
V	6	84	.943

Varying degrees of positive correlation between the two factors were obtained for six of the nine mazes. None of our values are as high as that obtained for Miss Hubbert's maze. There are, however, three exceptions to a uniform positive correlation; in these three mazes the errors were mastered in proportion to their nearness to the maze entrance. This lack of a uniform positive correlation can be interpreted in two ways. 1. If food satisfaction is an effective agency of elimination, its influence is overcome by some other selective factors which are peculiar to three mazes. 2. On the other hand we may suppose that food satisfaction is non-effective and that all of the above correlations (both positive and negative) are to be explained in terms of a single principle. The latter hypothesis is the preferable one.

Miss Vincent suggested in her paper the possibility that the ease of elimination is a function of the strength of the tendency to enter an alley, and that in a general way the relative attractiveness of the various alleys can be measured by the frequency with which they are entered. Cul de sacs with the greatest error score offer the most inducement to entrance, and the stronger the attraction, the larger will be the number of trials necessary for elimination. On this basis a negative correlation will obtain between the number of errors for each alley and the order of mastery. To test the hypothesis, the various cul de sacs were now ranked in the order of number of entrances made by the group for the successive stages in the mastery of the maze. Correlation data were computed by the ranking method with much detail but since these results were uniformly consistent for all stages of learning, we give in table II the values for representative stages. The first horizontal column states the correlation values for the various mazes between the order of elimination of the alleys and the relative number of entrances made by the group as a whole for the first trial. The second column gives similar data in relation to the total number of errors made during the second and third trials. The last three columns state the results in reference to the total number of errors made in the first five runs, the second five runs, and from the eleventh trial until the maze was mastered.

TABLE II

CORRELATIONS BETWEEN QUICKNESS OF ELIMINATION AND NUMBER OF ERRORS AT DIFFERENT STAGES OF LEARNING

Trials	I-a	I-b	I-c	I-d	I-e	II-a	II-b	III	IV
1	–.571	–.821	–.535	–.714	–.892	–.321	–.642	–.654	–.133
2- 3	–.535	–.643	–.892	–.857	–.643	–.107	–.321	–.300	–.166
4- 5	–.642	–.571	–.821	–.535	–.500	–.642	–.964	–.764	–.350
1- 5	–.714	–.892	–.750	–.857	–.857	–.143	–.642	–.758	–.116
6-10	–.857	–.857	–.678	–.750	–.857	–.857	–.571	–.518	–.583
11-until learned	–.500	–.785	–.857	–.535	–.321	–.928	–.000	–.973	–.866

With one exception, a uniform negative correlation was obtained, the values ranging from —.107 to —.964. The exception refers to the final stage in the mastery of maze II-b. This record hardly invalidates the uniformity of the results as this maze was mastered very easily and but few errors were made after the tenth run. In considering the validity of this correlation, the uniformity for all mazes and for the various stages of learning must be emphasized. A single correlation value may well be due to chance in view of the paucity of data for which the correlation was calculated. But chance is pretty well eliminated when the computation is repeated 54 times and consistent results are secured. We may then safely conclude that some degree of negative correlation obtains for all stages of learning between quickness of elimination and the tendency to enter the cul de sacs, that in a general way those blind alleys which for some reason offer little inducement to entrance are easily eliminated, while cul de sacs which present the most enticement to exploration are the hardest to master. This correlation is *a priori* logical, for it is reasonable to expect that the strongest tendencies will be the hardest to overcome. Our results thus establish one of the factors underlying the order of error elimination, viz., that this order is a function of the strength of the entrance attraction characteristic of the various cul de sacs. It is admitted that other selective factors may also be efficacious; otherwise higher correlation values should have been obtained.

The validity of the above principle of explanation is supported by the data of table III, giving the correlation values between the number of errors for the various cul de sacs and their spatial order in the maze. A positive correlation obtains for the six mazes I-a, I-b, I-c, II-a, III, and IV. In these cases the animals entered the various cul de sacs with a frequency roughly proportionate to their proximity to the point of entrance, and it was for these six mazes that a positive correlation was found between order of elimination and nearness to the food box (table I). In other words the first cul de sacs were entered the most frequently and were the last to be eliminated. In mazes I-d, I-e, and II-b, on the other hand, the animals for some reason entered the last cul de sacs more frequently than the initial ones (negative correlation between number of errors and nearness to entrance), and in these cases the final errors were the last to be eliminated (table I).

TABLE III

CORRELATIONS BETWEEN NEARNESS TO ENTRANCE AND NUMBER OF ERRORS AT DIFFERENT STAGES OF LEARNING

Trials	I-a	I-b	I-c	I-d	I-e	II-a	II-b	III	IV
1	.322	.929	.822	–.964	–.107	.000	–.607	.846	.750
2- 3	.250	.679	.036	–.928	–.107	–.392	–.214	.709	.666
4- 5	.232	.143	.215	–.321	–.750	.143	–.892	.373	.800
1- 5	.322	.715	.679	–.928	–.214	–.107	–.607	.846	.700
6-10	.286	.786	.643	–.250	–.500	.465	–.107	.573	.733
11-until learned	.215	.250	.179	–.285	–.071	.536	.393	.500	.417

It is thus the phenomenon of error distribution in the maze that demands explanation in order to comprehend the order of elimination. Our results enable us to offer but few explanatory suggestions in regard to error distribution.

1. The persistent tendency for rats to keep returning to the point of entrance after exploratory excursions operates to increase the number of entrances into the initial cul de sacs. This returning tendency is well known, and it is at once obvious that these returns must result in repeated explorations of the initial

cul de sacs. All other factors being equal, we should expect that the relative number of entrances into the various cul de sacs will be roughly proportionate to their nearness to the point of entrance. This influence of returns is further indicated by two features of the data: a. In mazes I-d and I-e there is a negative correlation between number of errors and nearness to the entrance, the greater number of errors being made in the final cul de sacs (table I). The opposite relation, however, obtains for mazes I-a, I-b, and I-c, in which the greater number of entrances were made in the initial cul de sacs. This difference in the distribution of the errors among the cul de sacs is due entirely to differences of the sensory character of the mazes, for exactly the same maze pattern was used throughout and the objective environment of the mazes was identical in all cases. Mazes I-d and I-e differed from the others in that an olfactory trail was laid either in the true pathway or in the cul de sacs. This trail produced several characteristic peculiarities of behavior, one of which was a noticeable diminution of the number of returns. Miss Vincent kept no separate record of the number of returns, but she noted this feature of the behavior and frequently discussed its significance with the writer at the time. The degree of returning also accounts for the different distribution of errors in mazes II-a and II-b (table III). Again the same pattern was used and the maze was located in the same objective environment in both experiments. The only difference consisted in the presence and absence of sides to the runways. Maze II-b was without sides and their absence caused the animals to follow one edge of the platform with their paws or vibrissae much in the same manner as did the olfactory trails. Following an edge caused a noticeable diminution in the number of returns and thus accounts in part for the difference of error distribution in the two mazes. b. The returning tendency is quickly eliminated in the course of maze mastery, and we should thus expect that the relative frequency of entering the initial cul de sacs will be gradually diminished during learning for those mazes in which returns are an effective factor in error distribution. Such a diminution obtains for mazes I-a, I-b, I-c, III and IV (table III). In all five cases there is a high positive correlation between number of errors and nearness to the entrance, but this correlation keeps decreasing with the number of trials; in other words the number of errors in the initial blind alleys is decreased more rapidly than for the final cul de sacs.

2. The sensory character of the maze influences the distribution of errors in other ways than by minimizing the number of returns. The tendency to follow the edge or an olfactory trail evident in mazes I-d, I-e, and II-b operated to reduce the total number of errors. This fact is well demonstrated in Miss Vincent's paper. The operation of the tendency was relatively more effective in the initial than in the final stages of learning, and Miss Vincent interpreted this fact as due to the shift in control from olfactory and cutaneous cues over to kinaesthetic factors; when the maze is run in terms of kinaesthetic stimuli, the trail factor is no longer present and the rat is subject to the enticements of curiosity, distractive odors, etc. I wish to suggest a similar explanation of the greater frequency of entrance into the final cul de sacs in these three mazes. Starting from the entrance box, the rats are at once dominated by the stimulus characteristic of the trail. This sensory trail is followed and possible exploratory excursions due to curiosity, fear, and other motives are eliminated. As a consequence relatively few errors are made in the first sections of the maze. As the final sections are reached, however, the dominance of the trail motive is weakened and other enticements begin to operate. The weakening of the trail motive may be conceived under such terms as habituation or adaptation. The strength of other motives such as fear, curiosity, and the returning tendency may progressively increase with the distance traversed; the concept of summation of stimuli may be applicable here. The strength of the olfactory stimulus from the food box must necessarily increase as the final sections of the maze are reached. One can hardly suppose that the actions of an organism so complex, alert, variable, and thoroughly alive as is the rat can long be continuously dominated by a single motive. Some shift of motives during a run must be presupposed irrespective of the explanatory difficulties involved. Our hypothesis then assumes that the animals in these three mazes start out on each run under the dominance of the trail motive which tends to prevent errors. As the final section of the maze is reached, there occurs a shift of motives, and these new motives, such as food odor, fear, curiosity, etc., tend to produce errors. As a consequence of this shift of motives

during each run the greater number of errors will be made in the final cul de sacs in these three mazes. It is also possible that the same principle, a shift of motives, will account for the greater frequency of entrance into the initial cul de sacs in the normal mazes; in this case the shift will be from fear and curiosity over to the food odor. The odor of food as the rat reaches the final sections should be sufficiently directive as to minimize the number of errors relative to those made when the animal's acts are controlled primarily by curiosity and caution.

3. The distribution of errors is influenced by certain peculiarities of the cul de sacs other than their positional relation to the point of entrance. Since the influence of this factor may vary according to the stage of mastery, a separate treatment is necessary for its effects upon the initial and final distribution of errors.

a. *Initial distribution.*—From the data of table III it is obvious that the initial errors (first five trials) are never distributed in the exact order of the spatial arrangement of the cul de sacs. A few blind alleys are generally responsible for the deviations, and these are listed in table IV. The first columns give the various mazes with the number of cul de sacs belonging to each. Each cul de sac is numbered in order from the point of entrance. In the column headed "plus" are listed those alleys in which the number of entrances exceeds that to be expected on the basis of a perfect correlation. In the "minus" column are those alleys in which the number of entrances is less than the normal. The first group of mazes are those in which a positive correlation obtains between the distribution of errors in the first five trials and the proximity of the cul de sacs to the point of entrance. In the last group of mazes the initial errors are distributed proportionate to the spatial contiguity of the cul de sacs to the food box. The five mazes, I-a, I-b, I-c, I-d, and I-e, are identical in pattern; in the first three the sensory conditions were such that the greater number of errors were made in the initial cul de sacs; in the last two, the first cul de sacs were the least attractive. In spite of this radical difference of error distribution in the two groups, the same cul de sacs are responsible for the deviations from a perfect correlation in every case. The first cul de sac is much less alluring in the initial trials than its position would justify. On the other hand No. 6 was invariably attractive for it was entered much more frequently than one would expect if the spatial order of the cul de sacs were the only factor determining the distribution of errors in the initial trials. Likewise No. 3 was relatively difficult in two cases, and No. 4 three times. Comparing mazes II-a and II-b of like pattern but with a different distribution of errors, we find that No. 7 is easy in each case while No. 4 tends to be difficult. Chance will account for the deviations in part, but chance can not invariably favor certain cul de sacs. The tendency toward uniformity in the character of the deviations for the same maze pattern must be due to peculiarities of the cul de sacs other than their spatial position in the maze. Certain ones are relatively easy to avoid, while others are prone to be entered.

The susceptibility of the animals to these favored cul de sacs is, however, an individual matter. In maze III, No. 8 received more than its due share of entrances, yet this alley was not entered at all in the first five trials by four of the sixteen rats; in fact one animal did not enter this alley once in fifty trials, while another rat entered but three times in fifty runs. This avoidance of the difficult errors by certain rats can in part be explained in terms of the habits acquired by those animals in traversing the first section of the maze. Let us suppose that the first section of a maze contains no blind alleys but consists of a series of runways so arranged as to necessitate alternating right and left turns of 90°. At the end of this section there is presented a choice between two paths,—a "straight ahead" error, and a turn of 90° leading to the food box. It is conceivable

TABLE IV

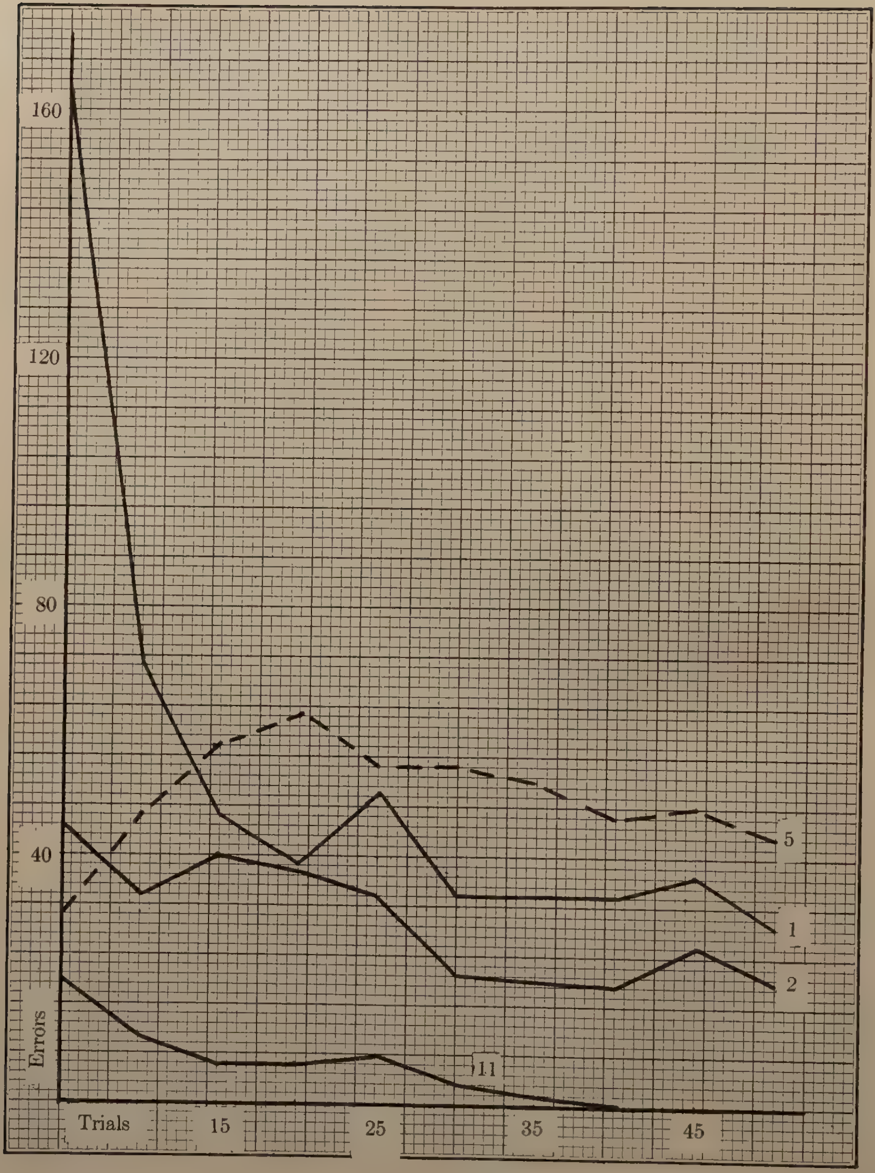
Deviating Cul de Sacs

Maze	Number of cul de sacs	Plus	Minus
A. Mazes exhibiting a positive correlation			
I-a	7	3, 6	1
I-b	7	4, 6	1
I-c	7	4, 6	1, 2
II-a	7	4	1, 2, 3
III	11	8	7, 10
IV	9	3, 4, 8	6
B. Mazes exhibiting a negative correlation			
I-d	7	3, 6	1
I-e	7	3, 6	1, 5, 7
II-b	7	4, 6	3, 7

that a choice between two such possibilities might be determined to a large extent by tendencies aroused in traversing the previous zig zag course. On this hypothesis the attractiveness of any cul de sac in a maze is in part a function of the motor tendencies developed in the prior sections of the maze. The habits aroused in a group of individuals in traversing the initial section of a maze must necessarily have much in common, and yet any part of a maze presents possibilities of wide divergence in the character of the pathway actually traversed. A group will thus approach a cul de sac with some degree of uniformity of disposition toward it, but radical exceptions are possible.

b. *Final distribution.*—The final distribution of errors represents the order of elimination, for eliminated cul de sacs are those which are not entered. As previously developed there is a correlation between the initial distribution of errors and the order of mastery of the blind alleys, but this correlation is far from perfect. It is thus evident that the order of elimination, or the final distribution of errors, is also dependent upon other factors than initial attractiveness. Certain peculiarities of the cul de sacs constitute a determining condition. Some blind alleys are relatively difficult and others are relatively easy to master, and this ease or difficulty of a cul de sac is to some extent independent of its initial attractiveness.

The above principle is well illustrated by mazes III and IV. The eleven cul de sacs of maze III fall into four rather well defined groups as to rate of elimination. The progress in mastery of four cul de sacs typical of these groups is represented by the curves of fig. 1. The alleys chosen as types are 1, 2, 5, and 11. The values represented are the total number of errors made by the group for each successive five trials. Curves 1, 2, and 11 illustrate the first principle that the order of mastery is inversely proportionate to the number of initial errors. No. 11 elicited but few initial errors and was mastered first; No. 1 was the most attractive but the most difficult, while No. 2 occupies a median position between the two. As to progress of mastery the three alleys are to be ranked in order, 1, 2, and 11. No. 5 is the exception which illustrates the influence of the second factor. This cul de sac was the hardest of the eleven to master, and yet its initial attractiveness was no greater than its position would justify. The number of entrances into this alley rapidly


160
120
80
40
Errors
Trials
15
25
35
45
5
1
2
11

increases for the first fifteen runs, and then slowly decreases for the remaining thirty-five trials. More errors were made at the end of the experiment than at the beginning. In considering the individual records, the general features of the group curve are also characteristic of that of fifteen of the animals. In maze III, the difficult group of cul de sacs is composed of alleys 5, 7, and 8. In maze IV, alley 3 was relatively easy while 5, 6, and 9 were the difficult ones.

This difficulty of any cul de sac must be explained mainly in terms of the animal's organization in reference to it, for all of the blind alleys of mazes III and IV were highly uniform in character. Each consisted of a single straight runway sixteen or twenty inches long. This reduction of the difficulty of a cul de sac to the animal's disposition toward it allows of a common explanation for both the initial and final distribution of errors. The disposition of an animal to enter or avoid an alley is a result in part of the habits of turning already developed. As the maze is mastered, these habits become profoundly modified. Returns and repeated explorations are inhibited and several cul de sacs may be eliminated. Since the attractiveness of a cul de sac is a function of the maze habit and this habit is altered in the course of mastery, it is evident that the initial and the final attractiveness of an alley must be to some extent independent variables. With this conception the disposition to enter an alley may actually increase as well as decrease, and individual exceptions to the group attitude are possible.

Such an explanation is feasible and the conception possesses some degree of *a priori* rationality, but any convincing proof of the hypothesis is more difficult. Chance can not account for the error curve of alley 5 in fig. 1, for the records of fifteen of the sixteen animals conform to its general features. There has been no objective change in the alley itself. Evidently it is the attitude of the animals towards this situation that has been altered. Nor will chance account for the distribution of errors of any individual animal. One rat did not enter alley 5 during the first five runs but made one entrance per trial for the remaining 45 runs. Another animal avoided this alley for eleven runs, alternated between success and error for the next six trials, and the error then became fixed. In another case this cul de sac was avoided twice, entered once, avoided twice, and then invariably entered on all succeeding runs. The eighth cul de sac was avoided six times, entered once, avoided once, and then became fixed; in another case it was avoided for 28 trials, entered three times, avoided for five trials, and then became fixed. The continual avoidance of an error for a number of trials followed by invariable entrance can not be due to chance. Chance may account for the first entrance but the *sudden fixation* of the habit remains inexplicable. This type of behavior may be readily explained by our hypothesis. This alley is so related to the previous sections of the maze that the turning habits necessitated by the latter dispose the animal to avoid it. But these determining habits become altered with successive runs. The avoiding disposition becomes weakened and finally supplanted by the opposite attitude. The alley is thus regularly avoided for a while; there is indecision and alternation for a short period; and this behavior is followed by sudden fixation and invariable entrance. The fixation of this error is not due to repeated entrances. In a sense this error was engrained in the animal's organization before it was entered, because the disposition is the outcome of the entire maze[4] habit developed up to that time.

CONCLUSIONS

The temporal order in which the various cul de sacs are eliminated is roughly correlated sometimes with their spatial order in reference to the food box and sometimes with their order of proximity to the point of entrance.

The temporal order of mastery of the cul de sacs is invariably correlated with their order representing the increasing number of errors made in each. The ease or rapidity of mastery of any cul de sac is thus inversely related to its degree of attractiveness as measured in terms of number of entrances. The problem as to the order of elimination of the cul de sacs must be explained in large part in terms of the distribution of errors.

The factors influencing the distribution of entrances among the cul de sacs are the tendency to return, the character of the motives actuating the animal, and peculiarities of the cul de sacs.

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[4] This hypothesis is closely related to Peterson's conception developed in his recent article, Completeness of Response as an Explanation Principle in Learning, Psych. Rev., **23**, 153-162.

The amount of returning will vary with the animal, the maze, the stage of mastery, and the section of the maze.

The character of the motives will shift within a run as progress is made from section to section, and from one stage of mastery to another.

The attractiveness of cul de sacs due to peculiarities of construction or position must in part be interpreted in terms of the animal's organization in reference to them. As a possible hypothesis, it is suggested that these disposing conditions of the organism are a function of the maze habit as developed up to that time. With this conception the individuals of a group may vary in their attitude toward a cul de sac and the attitude of any individual may change as the maze is being mastered.

MOVING AND STILL LIGHTS AS STIMULI IN A DISCRIMINATION EXPERIMENT WITH WHITE RATS

CORA D. REEVES

The work here reported was done in the spring of 1912 under the direction of Prof. J. B. Watson, by whom the problem was suggested. As the work of others may be furthered I present briefly results compiled at the close of the experiment.

Apparatus.—The apparatus consisted of two crayon boxes, 9.3 x 10.5 x 16 cm., blackened inside and out, and each with a doorway cut in one end. To each, on the end opposite the opening, was attached a narrow, vertical support with a horizontal bar on the top of it. Suspended from this bar and immediately above the door was a miniature tungsten, 2 c.p. lamp, thus:

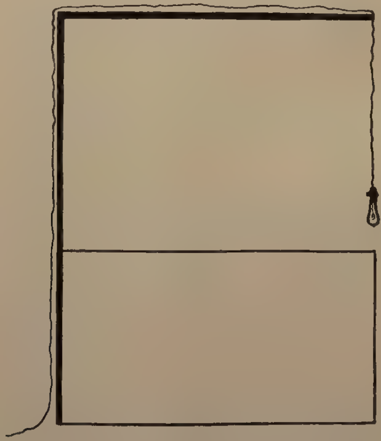

FIGURE 1.—Elevation of food-box

Rats tested.—The animals used were four male albino rats of the same litter. They had learned the maze but were not yet quite full grown.

Methods.—The boxes were placed upon the arc of a circle of 80 cm. radius near the end of a black-slate table of about a meter width. The following diagram will show conditions:

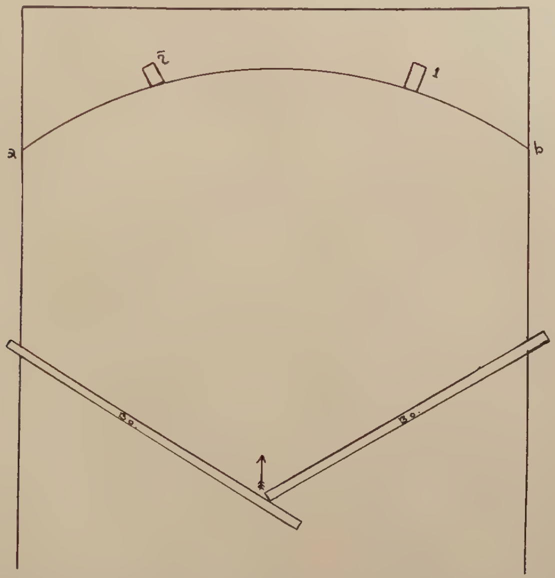

FIGURE 2.—Plan of apparatus. 1, 2. Food-box. Bo. Boards six inches wide which were placed on edge so as to pen off the area used in experimentation. a, b. Chalk line along which boxes were shifted. ←— indicates the position where the rat was placed and direction of the head.

Boards were used to close off the rest of the table. The experiment was carried on in a dark basement room and the black boxes were on the side of the room and of the table away from the light. Thus two dark objects against the dull background of the walls rested upon the slate table. Above these were the lights. The rats were kept in cages in the animal room and brought in a small wire cage to the room where the experiments were conducted. Before the rat was taken from the carrying cage a bit of food (bread soaked in milk) was placed in a dish in each box. A net was placed over the dish which was not to be in the food box for the rat being tested. The food and net were low in the dish and out of sight. This was to provide the same sensory stimuli in all particulars except the one to be discriminated. The light over the one box was started swinging by hand, moving through an arc of more than three inches and the light over the other box was left hanging still. The rat was dropped upon the table at the center of the circle (see fig. 2) or 80 cm. from each box. Care was taken to place the animal with head in the direction indicated by the arrow. A record of the time taken by each rat in reaching the box, and as to whether the choice was right or left hand, was made. The boxes were interchanged by chance. They were placed along the arc of circle at all points and all distances apart. The same box always had the light swinging. When the box had been reached and entered the rat was allowed to feed if correct choice had been made, and was then picked up and returned for another test. Two rats, A and B, were fed at the box with the still light; C and D at the one with the swinging light. The first days, ten trials were made each day for each rat; then twenty trials daily for the seven weeks the experiment continued.

Preliminary work.—The rats were put on the table and the time taken for them to reach a single box without light for 10 trials each. During these preliminary tests no food was placed in the boxes. The average time per trial was 32 seconds the first day. The second day A went to the box ten times, but B, C and D went to the box three, five, and five times respectively, then quit running about before reaching the empty box. The next two days food was put in the box; the average for the four was 9 seconds the first day, and 4 seconds the second day.

The following two days the two boxes were placed one with food and one without food. The average time for the rats to reach the box was 5.5 seconds for the first day, and 3.1 seconds the second day.

The following day the light was put above the food box and not made to swing. The rats A, B, and D behaved as on days when the light had not been there, at least, any hesitation if present was not sufficient to change materially the average time. The rat C, however, after two trials took a longer time each trial, looking at the light before starting and then refused to move when placed on the table.

The next day the light was started swinging over the one box while left still over the other. The conditions of the experiment had thus gradually been reached. The average time per trial for A, B, and D on this day was 1.7 seconds, for C 4 seconds.

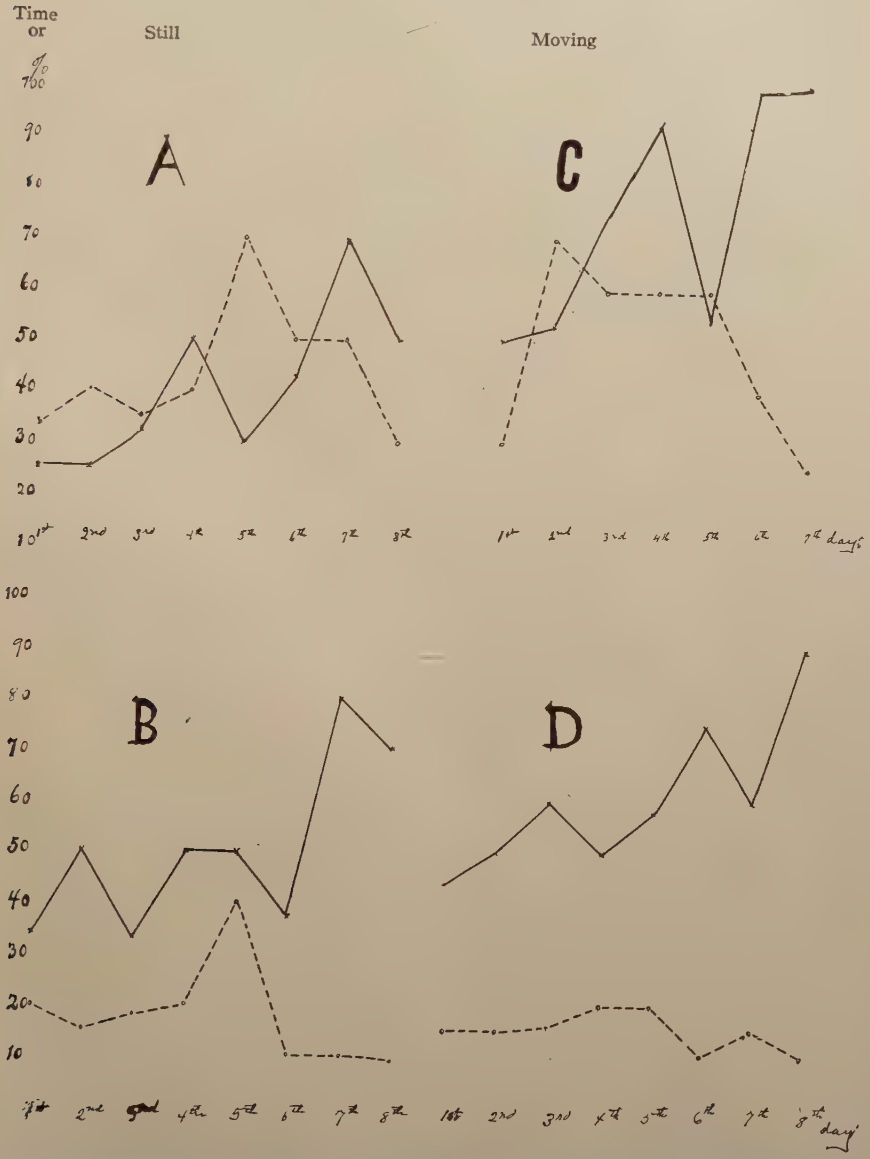

FIGURE 3.—Curves showing first responses of four white rats to stationary and moving lights. ———Per cent of correct choices for each successive ten trials. - - - - - - Average time in tenths of seconds.

The experiment.—Both A and B formed a rather persistent habit of going to the left hand box so that the first day's records of per cent of food choices have no significance. The days following, this habit was weakening and the correct choices increased. The preceding curves, fig. 3, show that A was slow in response as was also C, while B and D were habitually quicker in response. The curves show also that there was learning where the rats went to the moving stimulus, but with the others less high percentages of correct choice were made. Some tendency to decrease the average time for the day appeared.

On the eighth day, after two days of perfect record, the rat C was terrorized by a stranger with a dog entering the laboratory while this rat was on the table. An attempt to get again two days' perfect records caused the work to be prolonged for two months. After about two weeks (160 trials for each rat) the number of trials per day was increased to 20. There was an immediate increase in the average time per trial as shown by the following curve, fig. 4, which is made up from the time records of the four averaged for successive trials. The later trials for each day were slower. Evidently though only small portions of food were allowed each time the hunger stimulus was lessened after a few successful trials.

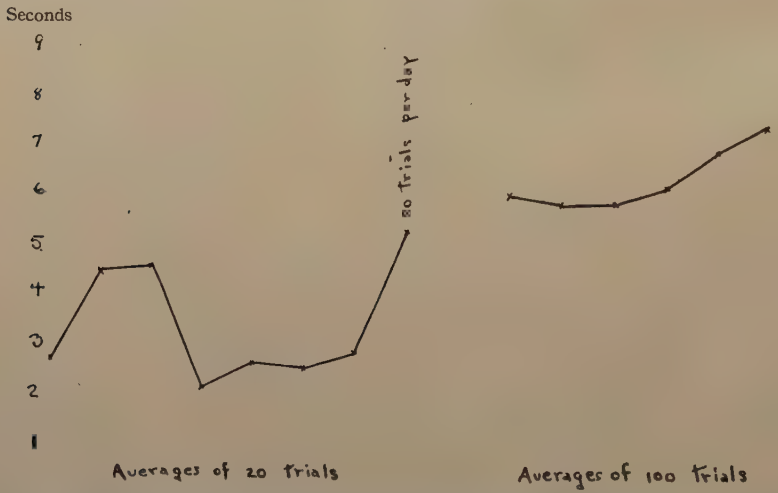

FIGURE 4.—Curve showing time in seconds for response to stimulus for four white rats while discriminating between still and moving lights during successive trials.

The first part of the curve is made by averaging together the averages of the successive 20 trials of each of the four rats; the last part the averages are for 100 consecutive trials.

The increase of time toward the end of the experiment is not easily accounted for. The age of the rats may be one factor. They, however, were not old but were then only full grown. The weather was warmer, and temperature and humidity may be other factors. The rats A and C were from the first (shown in fig 3) until the last days slower than B and D. For C the time average for the last 80 trials was 30 seconds. There is, then, no correlation between accuracy and speed of response. The rat A was the only one that toward the close of the experiment showed a reduction of the average time. Reference to the table which follows will show that the per cent of correct choices for this rat increases remarkably with the last 100 trials.

TABLE SHOWING AVERAGE PER CENT OF CORRECT CHOICES IN DISCRIMINATION OF STATIONARY AND SWINGING LIGHTS

	1st 100	2nd 100	3rd 100	4th 100	5th 100	6th 100	7th 100
Food at stationary lights:							
Rat A	40	40	61	57	69	69	90
Rat B	57.5	52	53	64	58	63	78
Average	48.2	486	57	60	63.5	66	84
Food at swinging light:							
Rat C	76.5	66	68	71	76	86	86
Rat D	55	68	58	68	68	77	87
Average	65.7	67	63	68.5	72.5	81	86
Averages	57	56.5	60	65	68	71	85

The slowness and difficulty of establishing this discrimination is apparent from the table.

The error curves (fig. 5 on page 166) show the same slow process of learning to discriminate and further emphasize the tendency of the rats to go to the moving rather than the still light. The use of only four individuals makes the results less certain than would be the case had a larger number been used.

The records of rat A have frequent notes, as "Watching, moving back and forth, swinging or nodding while advancing."

This diagram of a path taken by A (fig. 6) shows a frequent sort of behavior for this individual, which was being fed at the still light. The starts toward the moving light were frequent and were followed by a pause and a run toward the still light. The swaying or nodding motion, rhythmic with the light, was

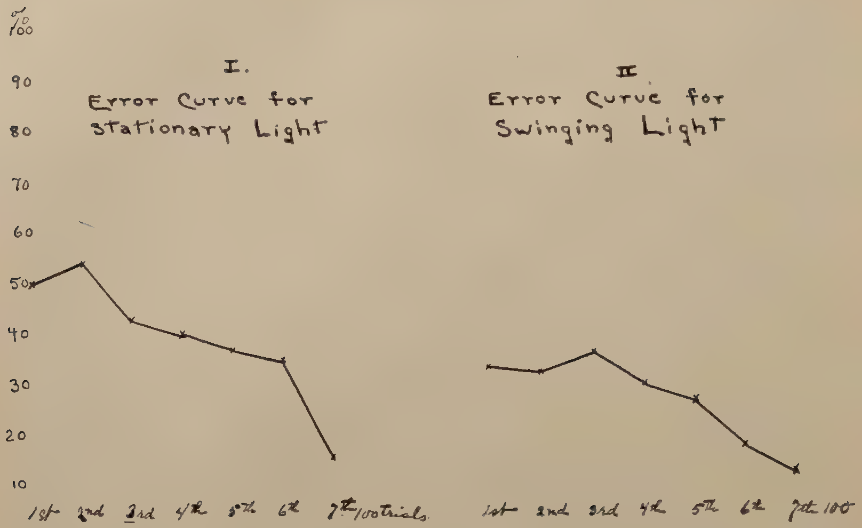

FIGURE 5.—I. Curve of error for rats A and B, fed at the stationary lights. II. Curve of error for rats C and D, fed at the moving lights. These show the average per cent of errors for each 100 trials.

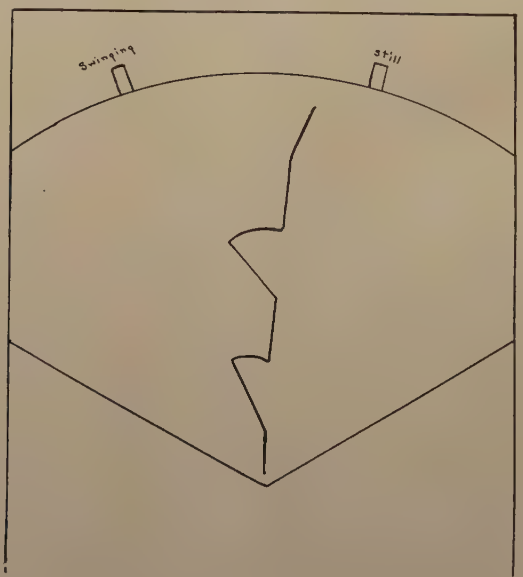

FIGURE 6.—Path taken by rat A in reaching the stationary light.

observed in rats A, C and D. While C and D started toward the still light at times, I have no records of paths of repeated starts and halts with change of direction as in the case of A.

Testing results.—To determine whether some clue given by the experimenter might not be the ground upon which the rats discriminated, Dr. Karl S. Lashley kindly tested the rats in my absence. There was an average of 80% of correct choices. In order to test further the significance of the results the rats which had been trained to go to the still light were placed as usual but with both lights still. They went equally to either box. A strange reaction occurred, for upon coming to the doorway of the box whose lamp had been swinging, when the vibrisse lightly touched the edges, rat A stopped, squealed, turned back and went over to the box which had had the still light. Apparently some sensation from contact dominated his reaction. The same halt at the doorway occurred when the rat C was presented with both lights swinging and he went to the box which had had the still light. One day when the rats trained to go to a swinging light were presented with both lights swinging in the middle of the day's series, the rat C for the four tests given, went to the box where accustomed to feed, but when the lamp which had been stationary was set swinging, while the light previously made to swing was still, this rat went to the box with the swinging light. D, when both lights were swinging, went to either box. The per cent of choices of the food box changed for this rat from 94 under standard conditions to 40 when both lamps were in motion. In other words, they went freely to the box which they had consistently avoided when the light stimuli were reversed. This fact together with the fact of the halt upon touching with the vibrisse the wrong box seemed conclusive evidence that the lights and not some other factor had been the effective one in making the choice when at a distance. After this halt at the doorway I noted that the small roughnesses of the edges of the doorway made by the saw were, of course, not exactly alike. I suspected that by chance or from attraction of the swinging lamp the rat C went to that box often and was then able to track himself but the evidence seems conclusive that the moving stimulus came to be the stimulus depended upon in reaching the box and food.

Discussion of results.—The large number of trials (700) necessary to establish this discrimination seems to indicate how small a part the visual stimulus, has in the daily life of a rat. Had it not been for the records of the first week and especially of rat C (fig. 3) and the lack of any adequate explanation other than "learning to discriminate" which would account for the improvement both in choice and in time, the conclusions (after each had had 200 trials) would have been that rats cannot discriminate a moving and still light. (See table.) The rats came in time to select the food box more accurately. In the fact that the rats halted at the doorway of the boxes where they had not been receiving food is an indication that they used other criteria than the lights when they reached the food box. They were, however, not able to select the right box when the condition of movement of the lamps was changed. It seems possible that some laboratory failures to find that animals possess as acute sensory mechanisms as have been popularly ascribed to them may be from the fact that the problem presented was not fitted to the animals tested. This incident will illustrate. At the close of this series of experiments an old rat which had been handled continually for some months was running about the room when the writer chanced to be winding up a piece of cord. As the end of the cord was drawn along the floor the rat followed, patted the end, for some eighteen inches, as a kitten would. This rat was tested several times with a cord but would never repeat the behavior. The rat became familiar with a new situation quickly but the stimulation afforded by a moving object could not be doubted. The effectiveness of movement in controlling reactions is shown in the difference in the curves (fig. 5) and in the path of the rat as shown in fig. 6. The lengthened average time when 20 trials per day were used instead of 10 confirms the evidence already presented that a large number of daily repetitions is not the most advantageous method of establishing a given discrimination.

CONCLUSIONS

1. Rats can and do discriminate a stationary from a moving light.

2. Rats show some tendency to approach a moving rather than a stationary light.

A NOTE ON THE INTERFERENCE OF VISUAL HABITS IN THE WHITE RAT

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INTRODUCTION

The following experiments were performed at the University of Texas under the supervision of Professor W. S. Hunter,, from January to June, 1916. This paper should be considered as a continuation of researches made by him and should be read in connection with his paper on "The Interference of Auditory Habits in the White Rat."[1] The purpose of the present tests was to obtain data showing the strength of habit in the white rat by measuring the effect of a habit previously acquired upon the formation of a new habit of opposite character. The stimuli in each case were lights. The results appear to reinforce the conclusions reached by Dr. Hunter, viz., that a habit acquired by training does persist in the new work and may interfere tremendously with the formation of a dissimilar habit. My detailed conclusions will be presented at the close of the paper.

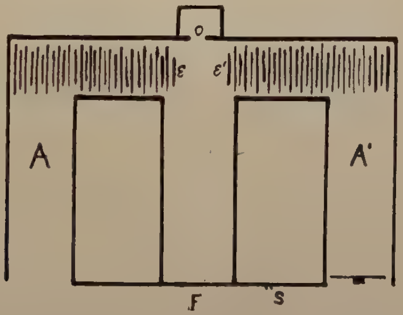

FIGURE 1.—Ground plan of the apparatus

The apparatus used was a T-shaped discrimination box and is shown in fig. 1. A mazda light was placed in a small box behind the main apparatus. Between the boxes was an aperture, O, covered with a piece of clear glass and a variable number of sheets of typewriter paper (Post Office bond). These variations and the c.ps. employed will be given below. The light was controlled with a switch at S. The rat was expected to react to the presence or absence of light by turning to the left or the right as the conditions of the experiment required and as will be detailed later. When the reaction to the stimulus was correct, the animal escaped through an open alley (A) to food at F; when incorrect, an electric shock was given by means of the wires marked E and E′ and a free exit was blocked by means of a movable end-stop, placed in the alley A′. At each trial the rat was introduced directly into the discrimination box through an opening at F and the stimulus was presented immediately. Punishment and reward was used throughout the test. The following series of presentations were used, 10 trials daily:

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[1] *Jour. Animal Behav.*, 1917, 7, 49-65

l l r l r r l r l r
r l l r r r l l r l
r r l r l l r l l r
l r r l r r l r l l

EXPERIMENTAL RESULTS

I

The present experiment was begun with four untrained rats (adults). Later four new untrained rats were added. Of these one (No. 10) was 42 days old; one (No. 13), 37; and two (Nos. 14 and 15) 68 days old. Unless otherwise stated the results given are for all eight rats.

On each of 3 consecutive days the animals were allowed to make 5 preliminary runs in the box, the object being to acquaint them with the apparatus and to accustom them to receiving their food at F. These trials were given without light stimulus, punishment or end-stops, save that the latter were used where necessary to prevent the appearance of position habits.

In the regular test, habit No. 1, a correct response required the rat to turn through the right hand passage when light was present and through the left hand passage when the light was absent. The light used in this first test was a mazda 32 c.p., shaded by one thickness of ordinary writing paper as mentioned above.

Table 1 shows the number of trials required by the rats in establishing the association. The standard of learning was as follows: Each of the last four series of 10 trials must show at least 8 correct reactions, but the average percentage of correct reactions for the four series must not be less than 87½%. The trials in table 1 include all given each rat up to the 40 made at the standard percentage.

TABLE 1

LEARNING HABIT NO. 1

Rats	Trials
1	170
2	180
3	80
4	190
10	300
13	220
14	60
15	120

A comparison of table 1 with similar data obtained by Dr. Hunter in his experiments on the acquisition of auditory habits[2] is of value in showing a greater ease in the formation of visual habits by the white rat. My rats ranged between 60 and 300 trials with an average of 152. Dr. Hunter's rats,—from the same stock, working in the same apparatus on the same problem, but using sound as a stimulus,—ranged between 210 and 710 trials with an average of 423. This is a matter of great importance inasmuch as the explanation would appear to lie chiefly, if not wholly, in the different sensory channels involved. I call to mind no prior demonstration of this fact. Extended study, which would go far beyond this preliminary work, would undoubtedly reveal important differences in vision and hearing so far as the daily life of the rat is concerned.

As each rat learned the association, control series were introduced as follows:

1. No light used; no punishment. Reaction considered right if it fits the series.
2. An 8 c. p. mazda substituted for the standard light. Punishment used.

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[2] Op. cit., table 1.

The object of control 2 was to determine the similarity of the 8 and 32 c.p. stimuli in terms of response. A summary of the control tests is given in table 2. The chronological order of records has been preserved. The per cents represent correct responses in a given daily series of 10 trials. The low percentages made with control 1 indicate the rats' dependence upon the light as a determining stimulus. The high percentages made with control 2 indicate that the rats sensed the light and that it meant to turn to the right in order to secure food. The exceptions to this statement are shown in the table.

TABLE 2

Controls Used With Habit No. 1

	Rats							
Control	1	2	3	4	10	13	14	15
Control 1......	50%	80%	40%	50%	60%	60%	50%	50%
Control 1......	..	60	..	..	..	..	..	..
Normal.......	90	100	90	100	90	100	90	90
Normal.......	..	..	..	..	..	..	90	..
Control 1......	50	..	60	50	20	50	40	70
Normal.......	100	..	90	90	60	100	90	90
Normal.......	..	..	..	..	90	..	..	..
Control 2......	50	90	70	80	80	100	70	100
Control 2......	..	80	..	..	..	..	..	..
Normal.......	60	100	90	90	90	100	70	100
Normal.......	100	..	..	..	..	..	..	..
Control 2......	50	60	70	70	70	90	40	80

II

Training on the second habit was instituted in the case of each rat as soon as the results of the first test had been analysed by controls as shown above. The second habit furnished a problem the opposite of habit No. 1. Its purpose was to train the rats to associate turning to the *left* with the presence of light and to the *right* for the absence of light. The 8 c.p. light of the control tests was the stimulus here. At first it was shaded by three thicknesses of the writing paper. But when rat No. 3, the first rat tested on habit 2, persisted in reacting to this stimulus as he did to the absence of light, I removed one thickness. The purpose was to secure a light which would be treated the same as the standard light and yet which should be as different in intensity as possible from the standard.[3] The situation is summarized in table 3. The first reactions of the rat to the twice-shaded, 8 c.p. light were made as though this light were the standard light of habit 1. (Reactions to the normal stimulus should give at least 80% correct. Reactions to darkness would all be made to the left and so would give 50% correct. Since the new series, habit 2, was the reverse of the "normal" series, when the rat treated the stimulus as though it were the normal standard light, he should make not more than 20% correct.) I now knew that the once-shaded 32 c.p. and the twice-shaded 8 c.p. would initiate the same responses. Furthermore, there was reason to assume, both from the behavior just cited and from the work of other investigators, that the lights were dissimilar enough in intensity (one being almost equivalent to darkness) that they could be readily discriminated by a rat when tested in the conventional discrimination box.

TABLE 3

Test	Correct in 10
Normal (32 c.p., once shaded)	9
New series (8 c.p., thrice shaded)	5
“ “ “ “ “	3
“ “ “ “ “	5
“ “ “ “ “	5
“ “ “ “ “	5
“ “ “ “ “	4
New series (8 c.p., twice shaded)	1

In this second test every effort was made to keep the conditions identical with the first test save in the matter of light stimulus and direction of turning. The results are very striking. In the first test, the least number of trials given any rat was 60 and the greatest 300. In the second test, one rat learned in 420 trials. The other seven rats never completely learned the association,—the trials given were 680, 760, 850, 1080, 1080, 1090, 1090, and 1160. At the close of the work these rats were improving so, that it seems probable that they would have mastered the problem had the training been more extended. The results of this test are summarized in table 3. The length of the training periods here as opposed to the learning periods with habit No. 1

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[3] It would be of value and interest to have animals form habit No. 2 with the same stimulus used in habit No. 1. My choice of stimulus for the second habit was guided by a desire to secure a procedure similar to that followed by Dr. Hunter.

TABLE 4

Correct Reactions in Each Succeeding 50. Habit No. 2

	Rats							
Trials	1	2	3	4	10	13	14	15
50	13	5	23	13	14	9	21	12
100	18	16	17	7	11	13	17	16
150	16	20	10	13	12	12	15	27
200	13	20	18	17	16	14	20	17
250	20	17	27	18	17	9	21	30
300	12	15	23	24	18	13	21	34
350	14	19	25	14	17	15	31	31
400	10	20	26	18	18	16	32	43
450	15	20	25	16	23	26	32	15 of 20
500	17	18	18	19	25	25	30	
550	19	19	25	21	28	27	41	
600	15	10	22	23	26	29	41	
650	17	16	22	26	21	33	34	
700	17	21	24	25	22	27	27 of 30	
750	22	17	28	31	27	26		
800	29	26	32	28	3	26		
850	22	24	29	30	of	24		
900	22	32	30	28	10			
950	25	27	30	41				
1000	27	35	32	33				
1050	30	41	27	33				
1100	26	20	29	24				
1150	of	of	31	of				
1160	40	30	7	40				
			of					
			10					

are not to be explained by variations in age (which were too small) or in experimental conditions. The essential factor is the interference of habit No. 1 with the formation of habit No. 2.

The following is a brief examination of representative data secured on habit No. 2. Rat No. 3 had acquired the first habit with great facility after 80 trials. After 1160 trials on the second association he was making only 31 correct reactions out of a possible 50. This rat when set upon the new problem was in perfect condition and had shown no tendency to untoward timidity or the formation of position habits. When presented with the second problem, he at first reacted to the stimuli (8-c.p. light for turning to left; darkness for turning right) as if they had been the former stimuli (32-c.p. light for turning right and darkness for turning left). Upon punishment he immediately set up position habits from which he could be forced only with difficulty and into which he fell again and again. Several times he slowly approached the standard of learning; but when he seemed about to attain it, the position habit would again appear. This conduct was characteristic of all rats, save that rat No. 15 did master the problem. This error-behavior need not be regarded in its entirety as an interference phenomenon, because it occurs in the course of all difficult problems. However, it is to be remembered that the present discrimination of light from darkness is not a difficult problem. Table 5 gives sample records illustrating the above factual statements concerning position habits.

TABLE 5

Diary Records Showing Fluctuating Behavior in Learning Habit No. 2

	Rat No. 4
April 27	8
28	9
29	5
30	5
May 1	5
2	6
15-22	8, 8, 8, 9, 6, 6, 7, 5
	Rat No. 14
May 16-28	8, 9, 8, 8, 8, 7, 7, 6, 10, 9, 9, 7, 4

III

Rat. No 15 was the only one who mastered habit No. 2. This animal was 68 days old when first tested. He acquired habit No. 1 in 120 trials (tables 1 and 2), was put through the controls and immediately started upon habit No. 2. This was mastered in 420 trials (table 4). A control similar to control 1, used in analyzing habit No. 1, was instituted and proved that No. 15 was reacting to the stimulus (light) presented.

A third problem was then set No. 15,—a test in retention. The rat was put back on habit No. 1, the operator again using as stimulus the 32-c.p. light (shaded as before in habit 1). The rat was tested for 15 days, 10 trials daily. Habit No. 2 persisted and interfered with the training on habit No. 1 so that the percentage of correct reactions never exceeded 50 for any 10 trials. By the close of the 150 trials a position habit of always going to the left had fixed itself upon the rat with such tenacity that tests were discontinued.

I have plotted three curves, fig. 2, which present graphically the learning processes detailed above. The curves are constructed as follows: The total number of trials given a rat prior to the 40 made at the standard is divided into 10 parts. The percentage of correct reactions in each one-tenth is then computed and an average for all rats taken. The resulting curve shows the progress of error elimination independently of the absolute number of trials and is thus representative throughout its length. N indicates the records during the 40 trials made at the standard percentage.

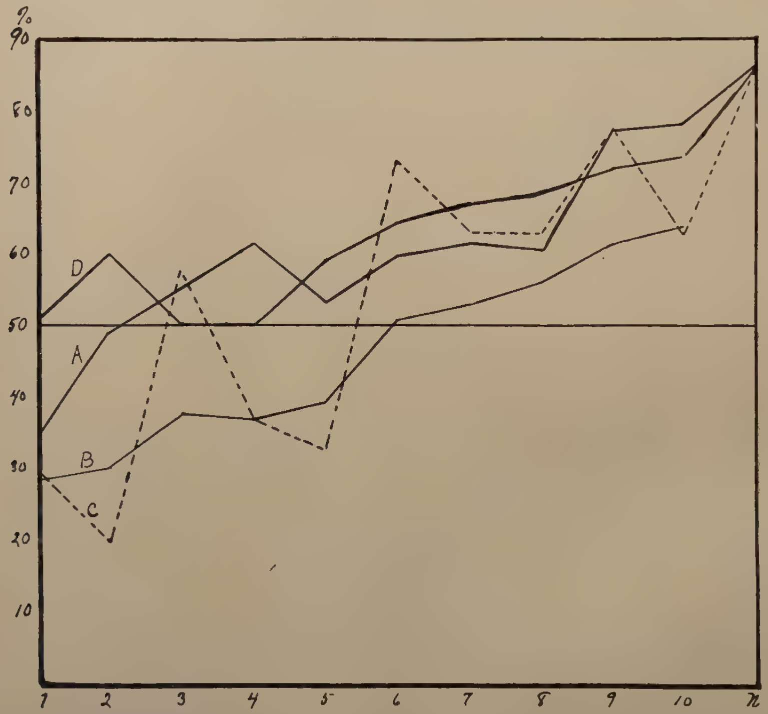

FIGURE 2.—Curves of learning. A—record for all rats on habit No. 1; B—record for all rats but No. 15 on habit No. 2; C—record for rat No. 15 on habit No. 2; D—record for Hunter's rats on learning a first habit in audition.

Curve A shows the succeeding average percentages of correct reactions for all the rats during the formation of habit 1. It is essentially the same as curve D. Curve D is taken from Dr. Hunter's "Auditory Interference" study, table 7. It is a normal curve of four rats on sound. The practical identity of the two curves is interesting in view of the different absolute lengths of time involved in the formation of the two types of habits.

Curve B presents the results for habit 2 for all rats save No. 15. It is a curve of progress and not of completed learning. Curve C is the record for rat 15 on habit 2. The curve is irregular in its first part. Curves A, B, and C indicate that so far as rate of error elimination is concerned, habit interference has been most prominent in the first six-tenths of the curves. Dr. Hunter's results also indicated that the six-tenths point was a turning point in the relearning process. The situation may be but a coincidence, however.

CONCLUSIONS

1. A simple visual habit of the type here studied will interfere tremendously with the formation of another visual habit of opposite kind. This interference may practically prevent the formation of the second habit.
2. A comparison of our data and Dr. Hunter's indicates that the white rat learns visual habits much more readily than similar auditory habits.

MODIFIABILITY OF THE PREFERENTIAL USE OF THE HANDS IN THE RHESUS MONKEY

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Observations on handedness in monkeys and apes has not, in general, given evidence for the predominant use of either hand which might be ascribed to heredity and in this respect has not provided phylogenetic support for the view that handedness in man is instinctive. Pfungst ('12) reported that in observations on over sixty individuals of different genera the instances of predominant use of either hand could almost always be traced to training or to previous trauma. He has not, however, reported the details of his work. Franz ('13) found that of six monkeys (Macacus rhesus) two were ambidextrous, three used the left hand more frequently than the right, and one was probably right-handed, but doubtful because of the small number of observations which could be made. Lashley and Watson ('13), studying a very young monkey, were unable to demonstrate the predominant use of either hand. Yerkes ('16) made tests upon seven apes, four of which were found to be predominantly left-handed, one right-handed, and two probably ambidextrous.

Except in the work of Franz not enough observations of any one animal have been reported to demonstrate such a persistent predominant use of one hand in a variety of activities as is necessary for a comparison of the condition in the animal with handedness in man. During the past summer Dr. Franz placed two young male rhesus monkeys at my disposal, suggesting a continuation of the work upon the preferential use of the hands with a view to the permanent modification of the normal condition by training.[1]

Observations were made first upon the preferential use of the hands in a number of different situations to test the effects of

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[1] These animals were purchased with a fund granted by the Carnegie Institution of Washington to which acknowledgment is here made.

the immediate environment upon the reactions. An attempt was then made to alter the proportionate use of the hands. As the animals were to be used in other experiments the time available for this work was limited and it was not possible to undertake a permanent modification of their activity: a successful suppression of such an instinct would perhaps require a year or more. Since the complete alteration of an instinctive preference would necessitate the production of an altered predominance in the use of the hands under conditions in which training had not been given, a question of primary importance for the problem is the possibility of transfer of training from one situation to another, and the time available was sufficient for a limited study of this. The observations upon the animals' behavior in different situations formed a basis for a test of such transfer, requiring that the training be carried out in only a part of the situations.

The observations were made upon the animals, in part while they were in the cages described earlier by Franz ('13), in part while they were fastened by a strap one meter in length to a swivel snap in the floor of the room where the monkeys were kept. In the tests upon the use of the hands in taking food the following seven conditions were used.

Animal fastened to the floor with the strap.—

1. Picking up food from the floor. The food was dropped as nearly as possible in front of the animals and within easy reaching distance.
2. Taking food from the experimenter's right hand. The food was held directly in front of the animal and about 10 inches from him, so that he could reach it equally well with either hand.
3. Taking food from the experimenter's left hand. The conditions were otherwise as in situation 2.

Animal in the cage.—

4. Picking up food from the floor of the cage.
5. Taking food from the experimenter's right hand. His fingers, holding the food, were thrust through the coarse wire netting of the front of the cage so that the monkeys did not need to reach out of the cage to get the food.
6. Taking food from the experimenter's left hand. Conditions were otherwise as in 5.

7. Taking food from a small table placed in front of the cage and about six inches above its floor. The animals had to reach through the meshes of the netting to get the food in this situation.

Except when holding out food in his hands the experimenter remained at a distance of about four feet from the animals during the observations. The animals were rather wild at first and about two weeks were spent in handling them and accustoming them to the experimenter before the observations on the preferential use of the hands were begun. The two were markedly different in temperament. The smaller (No. 1) was gentle and almost fearless, rarely hesitating to take food from the experimenter's hands. The larger (No. 2), on the contrary, was exceedingly wild and fierce, constantly trying to break his strap, when out of the cage, and striking and biting at the experimenter when food was offered.

The tests were made at irregular times but several of the situations were included in each day's observations in order to control temporal variations in the use of the hands. With few exceptions the results of observations on different days are in agreement so that we may be sure that they are not due to a temporary injury of one or other hand.

PREFERENTIAL USE OF THE HANDS WITHOUT TRAINING

The number of times which the right and left hands were used by the two animals in each of the seven situations is given in table 1. There is a considerable amount of variation, depending upon the different environments in which the animals were placed, but the behavior of each animal is fairly characteristic throughout. No. 2 was obviously right-handed, using the right hand almost four times as frequently as the left. No. 1 showed a less marked preference for the use of either hand and a much greater adaptability to the different situations. In picking up food from the floor of the cage, where he was least influenced by the presence of the experimenter, he used his left hand in over 90% of the cases observed; a fact which indicates a decided left-handedness. Where food was offered in the experimenter's hands, however, he reached for it in 81% of the trials with the hand homologous to that used by the experimenter. Under like conditions No. 2 was not influenced by the hands of the experimenter, using the homologous hand in only 55% of the cases.

TABLE 1

PREFERENTIAL USE OF THE HANDS UNDER DIFFERENT ENVIRONMENTAL CONDITIONS IN TWO RHESUS MONKEYS

Conditions of Test	Monkey No. 1				Monkey No. 2			
	Number of cases in which each hand was used		Per cent of cases in which each hand was used		Number of cases in which each hand was used		Percent of cases in which each andh was used	
Hand used	R	L	R	L	R	L	R	L
Monkey in cage, taking food from—								
a—experimenter's right hand	146	102	59.7	40.3	264	70	79.1	20.9
b—experimenter's left hand	46	155	22.0	78.0	174	42	80.5	19.5
c—floor of cage	23	243	8.6	91.4	120	57	67.2	32.8
d—table before cage	59	41	59.0	41.0	200	4	98.0	2.0
Monkey on floor outside of cage, taking food from—								
e—experimenter's right hand	386	47	89.1	10.9	158	8	95.2	4.8
f—experimenter's left hand	3	164	1.7	98.3	60	40	60.0	40.0
g—floor of room	133	192	40.9	59.1	30	46	39.4	60.6
All trials	796	944	45.7	54.3	1006	267	79.4	20.6

A like predominance in the use of the hands was found in reactions of defense. With the monkeys fastened in the middle of the floor the experimenter touched them lightly on top of the head with the tips of the fingers of his right hand. The monkeys reacted to this by striking at his hand or by attempting to grasp and bite it. The number of times in which each of the two hands was used in warding off the touch is shown in table 2. Number 2 was as markedly right-handed in this as in his food-taking reactions. No. 1 again appeared to be left-handed, but only to a slight extent.

The predominant use of the hands seemed associated with the positions assumed by the monkeys when kept alone in different cages. They ordinarily sat in one of the rear corners of the cage and the corner chosen was usually that which gave the greatest freedom to the hand most frequently used. Thus No. 1 sat with his right side near the side of the cage, leaving his left arm free, and No. 2 kept his right arm and side away from the side of the cage. Interchanging the monkeys in their cages did not seem to interfere with this custom, which seems therefore independent of the relation of the cages to other objects.

Marked variations in the use of the hands from day to day were noted. Not more than 25 trials in any one situation were given on a single day and in the majority of cases one or the other hand was used exclusively in each series of trials unless some disturbing element, such as the alternate use of the experimenter's hands, intervened.

TABLE 2

THE PREFERENTIAL USE OF THE HANDS IN DEFENCE FROM ATTACK BY THE EXPERIMENTER

	Hand used to ward off blow		
	Right	Left	Both
Monkey No. 1:			
Number of cases	70	122	13
Per cent of cases	34.2	59.5	6.3
Monkey No. 2:			
Number of cases	129	33	6
Per cent of cases	76.8	19.7	3.5

TRANSFER OF THE EFFECTS OF TRAINING

When a sufficient number of observations had been obtained to make the relative use of the hands in each situation fairly certain, training for the exclusive use of one hand was begun. An attempt was made to force both of the animals, when leashed to the floor of the room, to use only the left hand in taking food from the experimenter's right hand. The method of training was to withhold the food and to grasp or strike at the monkey's right hand whenever he extended it to take the food. No. 2 did not take kindly to this training. He would snatch at the food with his right hand, getting it as often as not, and when punished would refuse to reach again. After about 100 trials he could no longer be induced to make any attempt to get the food and further training had to be abandoned.

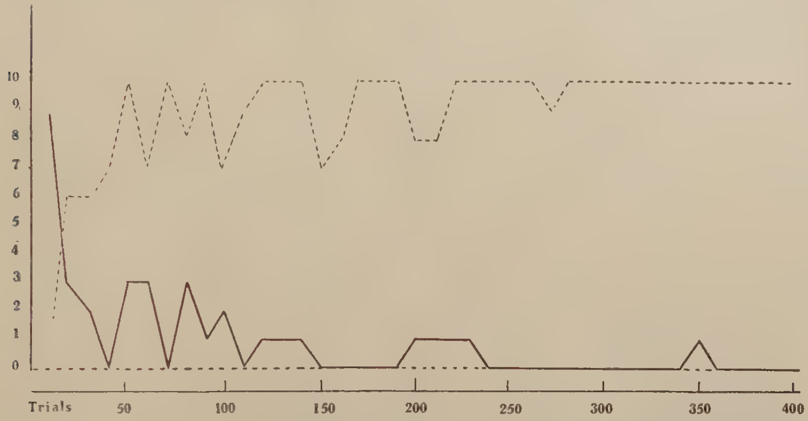

FIGURE 1.—The course of modification of the use of the right hand by training in the case of monkey No. 1. The ordinates represent the number of times that the right hand was used in each successive ten trials, the abscissae, the number of trials grouped by tens. ————first period of training. - - - - - - - - - - - - second period.

No. 1 learned to inhibit the use of his right hand very quickly. After nine successive failures to get the food with his right hand he began to use his left predominantly and only 34 failures to get the food were required to abolish completely the use of the right hand in this one situation. The form of the learning curve is shown in fig. 1. After the first hundred trials the left hand was used in all but 2% of his efforts to get the food.

When the habit seemed firmly established (after 500 trials) the preferential use of the hands in the remaining six situations was tested again. The data obtained are given in table 3. In the three situations outside of the cage the training resulted in a decrease in the use of the right hand. This is not very certain where the animal took food from the experimenter's left hand, since there was little room for improvement to begin with, but it is unmistakable where food was picked up from the floor. In contrast to this the training seems to have had little effect in modifying the use of the hands when the animal was in the cage, except in the last case, that of taking food from the table. The change here from 59.0 to 4.4% in the use of the right hand is significant.

TABLE 3

The Effect of Training in the Use of the Left Hand in One Situation Upon the Reactions in Other Situations. Monkey No. 1

Conditions of Test	Before training				After training			
	Number of cases in which each hand was used		Per cent of cases in which each hand was used		Number of cases in which each hand was used		Per cent of cases in which each hand was used	
Hand used	R	L	R	L	R	L	R	L
Animal on floor outside of cage; taking food from—								
a—experimenter's right hand	386	47	89.1	10.9	0	180	0.0	100.0
(Training in this situation)								
b—experimenter's left hand	3	164	1.7	98.3	0	95	0.0	100.0
c—floor of room	133	192	40.9	59.1	11	141	7.2	92.8
Animal in cage; taking food rom—								
d—experimenter's right hand	146	102	59.7	40.3	45	35	56.2	43.8
e—experimenter's left hand	46	155	22.0	78.0	14	62	18.0	82.0
f—floor of cage	23	243	8.6	91.4	14	59	19.0	81.0
g—table before cage	59	41	59.0	41.0	5	98	4.4	95.6

At the end of these tests training for the exclusive use of the right hand was instituted. The situation and method were the same as in the preceding training, with the exception that food was now withheld from the animal's left hand. After a very few trials he began to use his right hand and a total of only 40 failures was required to bring about the exclusive use of the right hand. The course of learning is shown by the dotted line in fig. 1. Tests for transfer of this training could be made only for the situation of taking food from the experimenter's left hand. The transfer was evidently complete for this condition, the animal using his right hand in 49 out of 50 trials.

DISCUSSION

With clear evidence for a transfer of training in some situations and not in others, we must ask the reason for the selection. The one character in common to the situations in which transfer occurred and differentiating them from the others was the presence of the wire netting of the cage between the experimenter and the animal. When on the leash the monkey was directly exposed to attack and in taking food from the table in front of the cage he had to put his hands between the wires of the front of the cage and so expose them to attack. The stimuli from the presence of the wire netting between the monkey and the experimenter seem, then, to have formed the limiting condition for the transfer of training.

An attempt at a further analysis of the rôle of these stimuli in determining the transfer is hardly justified by our present knowledge. In their cages the animals frequently give more threatening reactions than when held by a leash, so it may be that a certain physiological tone or emotional reaction, common to a part of the situations, reinforced the habit and led to its transfer to all of them in which it was present. The transfer might also be looked upon as the result of an analysis of the situations in ideational terms, but this and the concept of physiological tone are, themselves, so badly in need of experimental analysis as to amount to nothing more than a restatement of the problem when applied as explanatory principles. We can say safely only that the habit of using the left hand was conditioned by a complex group of stimuli.

The ease with which the predominance in the use of the hands may be altered by training will make it very difficult to establish the existence of any hereditary predominance. We never know the complete history of an animal or can exclude the possibility of a severe trauma which might condition the use of one or the other hand. Only the observation of the predominant use of one hand in a wide variety of situations and in situations entirely new to the animal could furnish reliable evidence for an hereditary predominance.

The possibility that the use of the hands by human infants may be equally easily modified by training makes the existing data upon handedness in young children of very doubtful value. Mrs. Woolley ('10) believed that the predominant use of the left hand by the infant which she studied was the result of the carrying position,[2] but experimental evidence upon the acquirement of such habits by young children is lacking.

SUMMARY

1. The rhesus monkey, as has been shown by Franz, may be right or left-handed or may use the hands indifferently.
2. Immediate adaptation in the preferential use of the hands in different situations may appear.
3. Where there is no decided preference, the use of the hands may be modified very easily for a given situation by training.
4. There is a transfer of training to new situations, but these are selected on the basis of complex stimuli.

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[2] Max Meyer ('13) has criticized this interpretation upon inadequate grounds. He says concerning it, " If our ancestral inheritance could be so easily modified as Mrs. Woolley supposes, what an incentive this would be to enthusiastic educators! " Here he evidently overlooks the fact that the great mass of habits formed by infants and young children (the social inhibitions) are just such modifications of instinctive behavor and that the modification is a process both rapid and productive of enduring results.

DIURNAL ACTIVITY OF THE EARTHWORM

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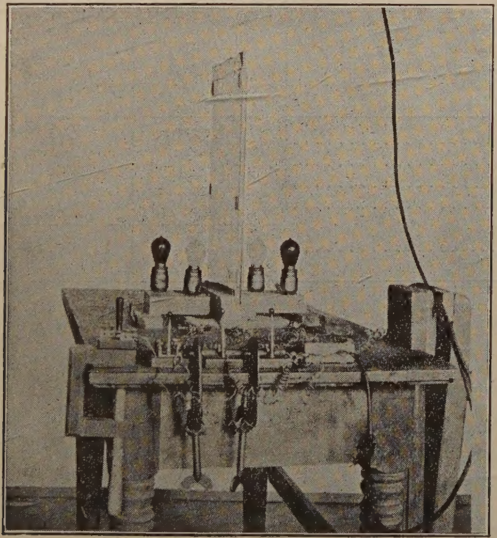
This note[1] records a series of observations made to determine whether the earthworm gives evidence of fixed periods of activity and of quiescence. Under the conditions of our observations, activity included (1) crawling movements either in or out of the artificial burrow, (2) feeding and the acquisition of food, and (3) the ejection of waste products from the body. Local contraction of segments was not regarded.

Apparatus.—Two parallel glass plates (12 in. x 20 in.), set 3-8 in. apart, were mounted in an upright position on a base 15 in. square covered at the lateral edges and filled in with



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[1] A summary of work done some time ago in the biological laboratory of Clark University, under the guidance of Professor C. F. Hodge. So far as the writer is aware, the work has not since been duplicated with this form. The author's thanks are due to Professor Bentley for suggestions in the preparation of the summary.

moist earth. Strips of black cloth were then tacked to a frame around the margin of the board, making a dark box to include the plates. Holes were cut in the cloth on either side for observation, a flap of cloth serving as a cover to the hole when not in use. Within were placed four 1-c.p. electric bulbs (two on either side of the glass) which were controlled by switches.

Large subjects of Lumbricus terrestris were used throughout the observations (four in the first series, and five in all the others). They were placed, one at a time, upon the surface above the plates and allowed to burrow into the soil beneath (between the plates), where their subsequent activity could be followed. The soil was kept moist by occasional sprinkling.

In preliminary observations, records were taken at 20-minute intervals, at various times of day and night throughout the period of one month. From data thus accumulated, the activity of the four subjects is summarized (in minutes) in table I, which indicates that the worms were active about one-third of the entire time with a fairly wide individual variation.

TABLE I

Subject	Total time observed	Total time active	Variations from average active time
I	18,060	7,740	2,324
II	18,070	6,000	584
III	16,200	3,840	1,576
IV	16,210	4,080	1,336
Averages	17,135	5,416	1,455

Records of the activity of five subjects were subsequently made on two different days (about a week apart), the observations being continuous for each of twenty-four hours. Table II displays the results for the two days (a and b), giving "active" times in minutes, by quarter-days.

Although moderate individual differences in amount of activity gain appear, the average active time, when compared with the total time of observation (1,440 min. for the whole day) closely approximates that shown in table I. It is further to be noted that the period of greatest activity, with but two exceptions (I-a and III-b), falls within the hours 6-12 P. M.

TABLE II

Subject	Days	A. M.		P. M.		Total active times	Variations from ave. time (373)
		12-6	6-12	12-6	6-12		
I	a	80	24	30	**252**	386	13
	b	48	45	**207**	147	447	74
II	a	54	126	12	**134**	326	47
	b	72	48	42	**195**	357	16
III	a	54	12	03	**218**	287	92
	b	**177**	32	**140**	126	475	102
IV	a	60	54	18	**186**	318	55
	b	66	108	60	**134**	368	05
V	a	...	52	30	**270**	352	21
	b	54	102	120	**137**	413	40
Averages						372.9	46.5

TABLE III

Subject	Days	A. M.	P. M.		Total active times	Variations from ave. time (259)
		8-12	12-6	6-12		
I	a	40	54	**236**	330	71
	b	10	54	**120**	184	75
II	a	35	78	**274**	387	128
	b	24	65	**115**	204	55
III	a	30	36	**73**	139	120
	b	70	70	**145**	285	26
IV	a	18	69	**138**	225	34
	b	19	60	**165**	244	15
V	a	12	45	**294**	351	92
	b	60	50	**135**	245	14
Averages					259.4	63.0

In a similar manner, the activity of five other subjects on parts of two days (a and b) is shown in table III. In this series the period 12-8 A. M. was not included in the record.

Again the ratio of the average active time to the total time observed is, in this case, very close to that given in table II

TABLE IV

Subj.	Days	A. M.	P. M.		Total active times			Variations from average times (211, 364, 156)		
		8-12	12-6	6-12						
I	a	54	144	66	264			53		
	b	78	66	168		**312**			52	
	c	..	11	126			137			19
II	a	..	60	65	125			86		
	b	84	144	156		**384**			20	
	c	..	48	132			180			24
III	a	60	138	72	270			59		
	b	104	140	174		**418**			54	
	c	..	48	78			126			30
IV	a	72	84	48	204			07		
	b	78	110	162		**350**			14	
	c	..	24	132			156			00
V	a	98	66	30	194			17		
	b	98	104	156		**358**			06	
	c	..	42	138			180			24
Aves..					211.4	364.4	155.8	44.2	29.2	19.4

(approximately 1:4), and again the period of greatest activity of the subjects is found to lie between the hours 6-12 P. M.

To determine the influence of food placed at the mouth of the burrow on the activity of the worms three series of observations were made and the results summarized in table IV. The letters under "Days" refer to the records of three successive days, before (a), while (b), and after (c) food was placed at the mouth of the burrow.

It appears from the above table that the presence of food at the mouth of the burrow tends to increase the activity of the worms, as indicated in the record of b. Activity is least upon the day (c) following its removal.

These observations lead us to conclude that (1) in spite of individual differences the total active time, when compared to the total time under observation, is fairly constant, that (2) the earthworm has definite active periods, confined, for the most part, to hours of the night, especially to the early hours of the night, and that (3) food has a decided effect upon activity.